Geological-Geotechnical characterization of the sedimentary basin of Loja and its correlation in the Foundations of Civil Works

Michael Valarezo, Walter Tambo, Alexander González, José Leonardo Benavides

***Abstract*— This article presents a characterization of the present practice in training San Cayetano and Quillollaco of the Hoya de Loja; what allows us to understand the behavior of the thin soils cohesive, the groundwater level and the measures to stabilization of soils with constructive purposes.**

***Index Terms*— Geotechnics, clayey matrix, relative consistency, foundations**

I. INTRODUCTION

It's of vital importance to understand the geological and geotechnical behavior of the geomateriales in a process of territorial expansion, even more in areas of urban projection, because in these will be feasible a set of civil works and architectural designed to provide the basic services of a population continuously in growth..

Analyzing soil instability involves respond technically and a more accurate way, to two variables fully defined in the field: (a) type and soil properties present in a specific sector? Moreover, (b) is there or not presence of underground water and what is their influence? That is why, the research in reference aims to establish the guidelines for a geological – geotechnical survey as a basis for the orientation of calculations of shallow foundations in clay soils with influence of groundwater. It also define the variables that; using a GIS software tool (ArcGIS 10.1.), which allows to achieve a zoning to the susceptibility of mass movements in the more real context in a pilot area that sequentially, will be replicated throughout the Hoya of Loja.

In this article, is defined as "foundation work" that part of a structure (and in what follows by extension of a fill of land),

whose fundamental mission is the transmission to the land of its own weight and the supported loads by the same. Therefore, emphasis is made in the procedures for obtaining geological data and the more real sequence of the geotechnical exploration campaign.

The guidelines and experiences that are set out and formulated, try to help the projectionist in the phases of geological and geotechnical investigation at the time of planning minor buildings or sites of urbanization. It provides greater emphasis on a crucial issue in the processes of foundations, the fact to relate and understand the behavior of the clays (Illite, Kaolinita and Montmorillonite) with respect to water [1].

The analysis, interpretation and correlation of geotechnical information consider laws, principles and basic calculations as strains and capacities with regard to the clay. The information is not the subject of the structural analysis of the elements of foundation, much less explanations or calculations relating to criteria of the instruction of structural concrete.

The theme of research is supported by the imperious need to provide with methodologies of studies on issues of basic geotechnics in the Hoya of Loja,

Specifically with the sequence of the geotechnical exploration campaign validated for our area, the correlation and characterization of the geomaterials with the foundations and; the behavior of the clay soils of the Formation San Cayetano when they are influenced by water. Currently neighborhoods of the east and west flanks of the Hoya of Loja suffer implications in its structure and foundations by the presence of clay soils and geological faults, which, coupled with an inadequate urban planning generate in the population, characteristics of risk and vulnerability. In this last scenario, it is necessary to elaborate and specify the guidelines of own research involving the particularities of the Hoya de Loja (58.1 km^2).

The general objective of this study focuses in a geological and geotechnical characterization of the main types of soils and rocks that affect the instability of the pilot area (The track of integration of neighborhoods Angel Felicisimo Rojas) and its corresponding territorial planning.

II. MATERIALES AND METHODS

Is considered a campaign of geological and topographic survey at relevant scales to 1: 4000, preceded by a campaign of geotechnical exploration equally to detail, related direct methods (trial pits and wells) and indirect method (geo-electric) in geological formations characteristics of Loja, as are Formations San Cayetano and Quillollaco.

By the extension, was considered a pilot area relating the track of integration of neighborhoods (Angel Felicisimo Rojas) from the Sector La Algeria until the "Y" of new track to Catamayo, which represents 9.8 km. It was considered an area of primary research of 5.16km2 (516.52has) because it took 200 m. of influence from the axis of the track.

The research environment relates a pilot area that covers to neighborhoods and existing and expanding urbanizations; as:

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La Algeria neighborhood, urbanization of Teachers and workers of APUL-AGEUL, urbanization of the College of Civil Engineers, Ciudad Alegría, Punzara Chico, Cofradía Neighborhood, Chontacruz Neighborhood, Memfis Central, Obrapía, Ciudad Victoria, Bolonia, Ciudad Victoria, El Plateado (part of El Plateado High, Low and commercial port). The systematic process of intervention in the research describes techniques with field efficiency ascertained based on satellite location technology and margins of precision millimetric. The sequence methodology is described in three phases in Figure 1.

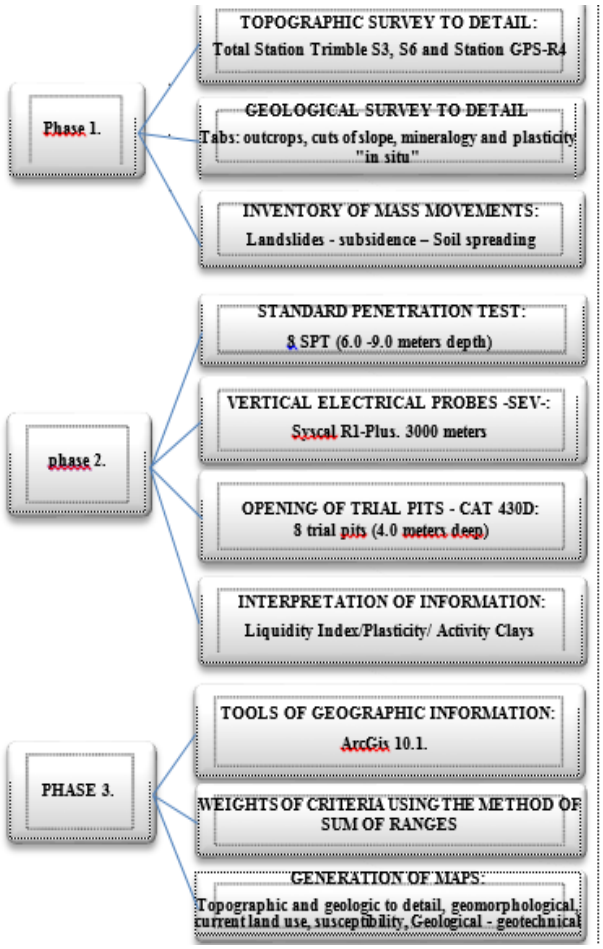

Fig 1. Methodological sequence for the geological- geotechnical survey in the Hoya of Loja.

In the identification, selection and evaluation of the components of susceptibility to landslides, was took into consideration the detailed knowledge of the area of study, which allows you to set the main variables acting as geomorphology, lithology and hydrology. The use of the GIS tool ArcGis 10.1 allowed analysis in set of different variables and obtain results with greater precision.

It was began to assess the different variables corresponding to geology, geomorphology, slope angle, the current land use and area of influence of the hydrography, by the method of the sum of ranges, see Table 1;

While the elements that compose it, are valued according to the criteria of experts with ranges of 1 to 5, being the lower number less prone to submit landslides and vice versa. Ayala-Carcedo and J. Corominas 2002[3].

Table 1. Weights of criteria using the method of sum of range and the formula for application.

NUMBER OF CRITERIA	WEIGHTS OF CRITERIA USING THE METHOD OF SUM OF RANGE					
#	W1	W2	W3	W4	W5	W6
2	0.66	0.33				
3	0.50	0.33	0.17			
4	0.40	0.30	0.20	0.10		
5	0.33	0.27	0.20	0.13	0.07	
6	0.29	0.24	0.19	0.14	0.10	0.05

Source: Janssen Ivan Herwijnen. 1994

The cartographic analysis of the susceptibility to landslide was carried out through the evaluation multicriterio (weighted sum) See Figure 2; and under the sequence of the construction model "model builder", see figure 3, established in the ArcGis tool 10.1. This model is an integrated set of procedures for data and tools that unfolds like a flowchart that runs in sequence.

So a model is used to simulate a real world event, which facilitates the understanding of the behavior of the studied phenomenon and makes it possible to predict possible results depending on the input data used (Gonzalez and Behm, 2008).

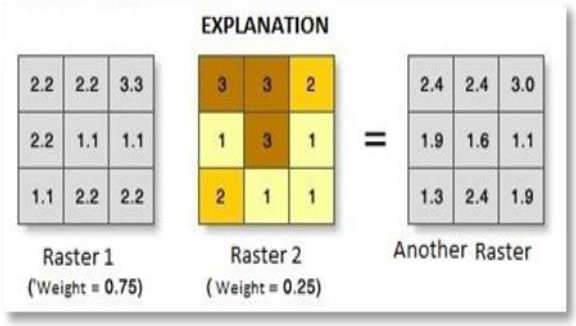

Fig 2. Tool Operating weighted sum, Source: Manual of Software Arcgis 10.1

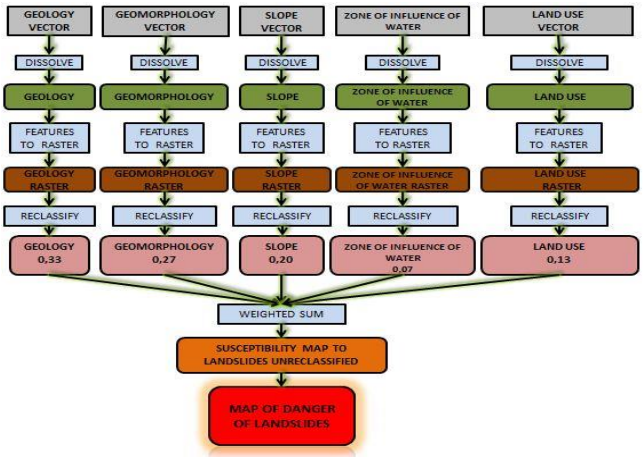

Fig 3. Diagram of Model Builder, Source: Researchers from the career of geology.

III. RESULTS

A. *Specification of the pilot area*

For perform efficiently the work of technical research, was required of an interdisciplinary group of engineers geologists, geotechnical, hydrologists, surveyors, mining, forestry, laboratory technicians or geo technologists and other specialists, who make up a team of work, in which is very

important to carry out the analysis with a mind very wide, without falling into dogmatism or simplistic conclusions.

The analysis and evaluation of a wide area as is the sedimentary basin of Loja, involves specify a initially pilot area with sufficient lithologic features, geotechnical and urban projection, which is representative for the whole sector to analyze. This means that, based on this pilot area, the sequence of exploration and analysis geological - geotechnical, may be replicated throughout the sedimentary basin of Loja, safeguarding the structural features of the area.

While it is true, the present investigation (specifically the geotechnical exploration campaign) is based on the experience of the professionals in charge;

There is to take very into account that *the experience can be a bad adviser*, because what happened in a site is not necessarily, what is happening in another site, much more if there is the presence of expansive soils and shallow groundwater levels.

The pilot area that includes the entire track of integration neighborhood (2013) was analyzed, from the Sector La Algeria until the turn of El Plateado (New Track to Catamayo). This track is funded by the Ministry of Transport and Public Works -MTOP-, with the support of the Municipal Government of Loja and develops on the west flank of the city of Loja in a north-south direction.

For geological - geotechnical analysis, the area of influence corresponds to 200 m. to each side of the track, which are measured from the axis of the track. This analysis geometric; in reality, covers more areas of influence, since when considering a landslide; for example, was measured from the top until the foot morphometrically talking.

This road system (connection from the national road network until connections to urban neighborhoods) comprises 15.50km, with an estimated investment budget of 29 million 400 thousand dollars; the culmination of the work according to the schedule of implementation, is planned for February 2015.

B. Research works carried out

Includes the campaign for recognition performed, which contemplated the specifications set forth in 0685, INEN NTE (1982) (Spanish): Geotechnics. Soil Mechanics. Terminology and symbology.

The geotechnical recognition of the terrain, classifies three groups or levels: T-1, T-2 and T-3 (favorable-intermediate-unfavorable) and describes the profiles correlating horizons A, B, C, D. In basis of these classifications and, with the general approach, were defined a series of guidance distances maximum between points of recognition and depths to be achieved by the SPT, while support for sampling is corresponds to the location of the SPT by geologic criteria.

The depths of the SPT vary between 6.0, 9.0 meters, and the SEV maximum ranges of 30 meters depth investigated. In the characterization of the strata, defined the geostatic tensional states (σ') at depths of 2.0 meters (relating a minor foundation), and 9.0 meters (as basis of depths to mass movements for the sector.

In the cases in which it reaches a geotechnical unit resistant (usually under the 5.0 meters deep), will be understood as one in which the pressures applied do not produce appreciable deformations. In such a context in the pilot area is considered a campaign with the guidelines for exploration by direct and indirect methods according to the following sequence:

Table 2. Activities related to the geotechnical exploration campaign.

DENOMINATION:	ACTIVITIES/DETERMINATIONS
GEOPHYSICS	• 3000 meters related to Vertical Electrical Sounding lines – SEV – • 4 lines of SEV by Sub-Sector
DRILLING SUB-SURFACE	• 8 -SPT- Standard Penetration Test • 1 SPT/ sub-zone • Depth range: 6.0~9.0 m
DIRECT SAMPLING	• 32 outcrops sampled "in situ" • 8 trial pits with depth of 4.0 m • Sampling based on the geology. By Fm.

Source: Report of field work. 11-2014.

For estimating, the accuracy of the information obtained has been resorted to the experience of the teacher researchers and their knowledge of rock mechanics, soil mechanics and geotechnical engineering. Likewise, should be aware that the deposits of natural soil on which the foundations are built, are not homogeneous in the majority of cases.

It is of vital importance to have a detailed knowledge of the geology of the Hoya of Loja. Our Hoya, is composed by a sedimentary sequence very varied, where the stratigraphic schema of deposition, were developed in two different areas with similar ages Cenozoic (Oligocene - Miocene). Figure 4. Geology in detail the pilot area 1: 4000.

Fig 4. Obtaining samples of the Shelby tube in the pilot area.

C. Correlation of the Atterberg limits and their influence in Geotechnics

Must be collected the geotechnical units relevant to consider in the study based on stratigraphic units indicated in the geology, identifying the geotechnical unit of greater and lesser resistance.

For each one of the relevant geotechnical units should be described the basic geotechnical properties, by placing approximately reasonable characteristic values of geotechnical parameters to consider. Its determination was made based on the criteria or geotechnical descriptions of the terrain in standardized format.

The Atterberg limits are world used in the classification of fine soils. Finding relationships between these limits and the properties of the soil has been the subject of research for many years. Terzaghi & Peck (1967) suggested the direct proportion between LL and the compressibility of the

soil. Sherard (1953) reported a similar behavior while investigating the effects of the "index" properties in the behavior of earth dams. Whyte (1982) suggested a method based on the extrusion for the determination of LP and found that the relation of resistance in LP compares with the relation of resistance in LL is of approximately 70. According Skempton & Northy (1953) this ratio is approximately 100.

Bowles (1996) reported a comprehensive collection of equations relating the indexes of compressibility and the plasticity of the soil.

These relationships can be useful in the orientation of the early stages of a feasibility study prior to the implementation of ground exploration and testing of its resistance [4].

The LL for clay minerals varies from 50 for the kaolinite to 60 for illite and up to 700 for the montmorillonite. The kaolinite and illite LP shows middle of 25 to 35, while the montmorillonite may have LP 100 (in Soil Mechanics Basic Concepts and Engineering Application. Aysen, A. 2002).

The LP is highly influenced by the organic content of the soil because it can rise his value without increasing the LL, by this soil with high organic content presented IP under and LL high. The limits fluids and plastics depend on the amount and type of clay in the soil. The index of plasticity IP, only depends on the amount of clay (of there the relationship of Skempton to define the activity of the clay, IP-based). The indexes will relate.

Table 3. Indexes obtained from the limits of Atterberg

INDEX:	DEFINITION:	CORRELATION:
Of Plasticity	I.P. = L.L. – L.P.	Resistance, compressibility, compactness, among other
Of Liquidity	$I.L. = \frac{W.n - L.P.}{I.P.}$	Compressibility, soil resistance and state of efforts
Of contraction	I.C. = L.P. – L.C.	Contraction Potential
Activity of the clays	$A = \frac{I.P.}{\text{Fracción de Arcilla } (\% < 2\ \mu m)}$	Potential for expansión and other

Source: Research Team of geology.

IV. Discussion

Guamán, G., in his report referred to Natural Hazards in the urban area of the city of Loja, reveals the existence of 93 landslides in 59.9 hectares since the year 1984 and that until now are maintained. This describes the abundance of mass movements caused mainly by lithologies from clay and silt clay bodies interspersed with sandstones and conglomerates in areas of very steep slope (greater than 30%).

In the present report it was determined the presence of damage to 33 neighborhoods; already before cataloged as high risks to geological-climate phenomena by GAD of Loja, 2008. It was also determined; that mass movements mostly are active and are more common in the formations Quillollaco, San Cayetano and Unite Chiguinda; which added to precipitation and rainfall intensity, increases susceptibility, risk and vulnerability of the Hoya.

The track of integration of neighborhoods (Angel Felicísimo Rojas), specifically from the sector La Algeria until Chonta Cruz, were identified and characterized fine soils cohesive, saturated and expansive; in such a way that substantially increases the possibilities in the sector landslides of any type. The urbanizations APUL-AGEUL, urbanization of Civilians Engineers, Ciudad Alegria, The Monastery of Sta. Clear of the Divine Child, La Cofradía; are the recent evidence of the events.

According to the "Geological-Geotechnical Study for identification of areas unstable in the urbanization APUL-AGEUL, province of Loja, Canton Loja"; the problem lies in the clay soils (30cm), stratums of siltstones and arcillolitas (12m), where the presence of surface water and groundwater (runoff, infiltration and percolation), have led to a myriad of landslides and differential movements [5].

Therefore, for the analysis of susceptibility to landslides in the pilot area (Track of integration of neighborhoods-Angel Felicísimo Rojas) is considered the heuristic method of the sum of ranges considering four variables that influence directly to the instability of the land: geology, geomorphology, slope and vegetation cover current land use. Through the topography and geomorphology to detail 1:5000, could be observed that the majority of land is plane and is located on the southeast,

Where they are building citadels as AGEUL, Ciudad Alegria and the urbanization of Civil Engineers, on the other hand, the topography with steeper slopes correspond to the north-west part in the sectors of Punzara Chico and Alumbre brook.

The geological-geotechnical description of the Formation Quillollaco indicates that it is composed of arcillolitas of grayish color, coffee-yellowish; and grain conglomerates medium to thick, with matrix clayey and clayey-sandy, of metamorphic angular edges ranging from five to ten cm in diameter with presence of iron oxides. There are also Quaternary deposits (coarse and fine coluvions) that have gradually filling cavities with remains of rocks as gneiss, quartzite and shale that were dragged into different events.

The geomorphology of the sector is represented by 9 forms of relief of the terrain: bodies in the shape of a horseshoe, old colluvia, saturated and dynamic concave slopes, soft concave slopes, convex slopes, wavy surfaces, surfaces higher slopes, escarpments, coluvio alluvial valley, thus determining that there is areas that favor the occurrence of landslides.

The variables that are used for the final map of susceptibility (ArcGis 10.1) are linked to the pending, because it is a factor that affects dramatically in the instability of the land; all this in order to have a more clear and accurate at the time of assigning weights [6]. After obtaining, the variables are proceeded to correlate the information, through the development of different digital models for obtaining the map of susceptibility that be more in keeping with reality.

The allocation saves an analysis similar to the method raised in the report "Natural Risks in the urban area of the city of Loja" (Guamán G., 2008) [7],

Which also relates morphology, morphometry (pending), lithology (types of rocks), land use and vegetation cover (physiognomy of the vegetation); dip of the layers and precipitation with annual averages with data of 30 years.

The field work consist in 9 trials of SPT with a variable depth between 6.0 and 9.0 m., obtaining as a result the characterization of geomateriales clay of medium to low plasticity, with a carrying capacity of 48.6 ton/ m2 to a depth of 2.0m., because is the base of the foundations. This is performed with the average data, the calculation of brake shoe to 0.8 x 0.8m., for buildings up to four floors, but it is not

recommended and standardized to 1.5 x 1.5 m., which if it is recommended.

With the calculation of safety factor was determined that the values are little favorable (FS=0.6~0.9) therefore it is necessary to implement the appropriate measures for stabilization and control in each one of the landslides [8].

V. CONCLUSSION.

The research details the sequence of geological and geotechnical exploration more feasible to apply in the Hoya de Loja; this covers three basic levels: topography detailed expanded to the geotechnical study (range 1:3), geology detailed, Geophysics (SEV) and direct visualization campaign and tests related to samples of SPT and trial pits. This campaign allows knowing the most viable and accurate as possible, the behavior of the geomateriales in geological formations San Cayetano and Quillollaco; as well as the determination and direct and indirect influence of the phreatic level in foundations.

The sequence of geological-geotechnical exploration, which allows for the characterization of the geological materials of the Hoya de Loja [9], first established the existence of seventy mass movements in an area of study of 5.16km2, which defines the sector with a categorization of susceptibility as shown in Table 4 and Image 1 and 2.

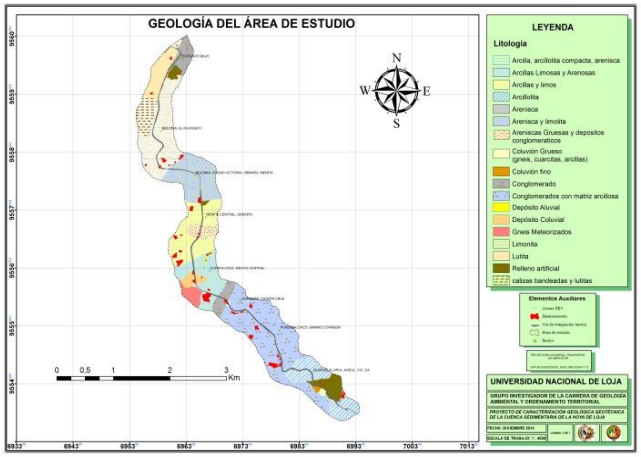

Fig 5.Geological map detailed the pilot area (Track of integration of neighborhoods Angel Felicisimo Rojas). Scale: 1:4000, Source: Geological Research Team .

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